Astrobiology Sample Acquisition and Return

A mission concept for 2018 / 2020 based on the MEPAG Mid Range Rover Science Analysis Group findings and extensive field testing data from Svalbard

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[1] All acronyms used in this document are defined in "Compiled Bibliographic Citations and Acronym Glossary for the Mars-Related White Papers Submitted to the NRC's Planetary Decadal Survey", which may be accessed at http://mepag.jpl.nasa.gov/decadal/index.html.

Introduction

A Mars mission concept idea entitled the "Mid Range Rover MAX-C" for the 2018 or 2020 launch opportunities is presently under consideration by NASA (1). This concept has been studied by a science analysis group (Mid Range Rover Science Analysis Group (MRRSAG)) who reviewed the National Research Council and MEPAG goals for Mars exploration in the next decade (1). The "MAX-C" mission compliments the ESA ExoMars mission and its primary goals are as follows; a) respond to life related discoveries and hypotheses in response to MSL and other missions, b) evaluate paleo-environmental conditions on Mars, c) characterize the potential for the preservation of biosignatures, d) access multiple exposures of layered sedimentary units in search of evidence of ancient life and / or prebiotic chemistry and e) access multiple geologic units representative of the Noachian era of Mars history. Samples of interest would be collected after analysis by on-board instruments, documented and packaged (Cached) in a manner suitable for return to Earth by a future Mars Sample Return (MSR) mission.

To achieve these goals the MAX-C mission would require; a) access to suitable outcrops, b) target selection capabilities c) rock/regolith interrogation suite capable of measuring chemistry, mineralogy, organic carbon and sample textures, d) detailed documentation of sample context and e) caching capability for future MSR collection. The MAX-C payload was not defined by the MRR-SAG. For the proposed concept, the following supporting system hardware would be needed; a robotic arm sufficiently scoped to accommodate the contact instruments to meet the mission objectives, a coring drill system and a caching system for drill cores and regolith compatible with MSR architecture. The MRR-SAG considered two straw-man payload concepts: one containing analytical suite capabilities and another consisting of a purely contact instrument suite. The advantages of the contact-suite-only architecture are (a) that it is significantly lower mass with a 15 kg scientific payload (suggested in (1)), and (b) it can conduct many spatially resolved measurements, interrogating more samples than can be processed with an analytical suite. The MSL surface operations scenario will require multiple sols for its analytical lab experiments, and the architecture we endorse will be less energy intensive, allowing further mass reduction in the supporting power storage and distribution system.

Our purpose is to show the validity of this mission concept by reviewing field activities on the ASTEP funded Arctic Mars Analogue Svalbard Expedition and to use this experience to define a MAX-C like concept mission and payload using Nili Fossae as a model site.

Heritage from Field Testing

The Arctic Mars Analogue Svalbard Expeditions (AMASE) from 2006 to 2009 were the latest of a series of expeditions that are NASA, ASTEP, and ESA funded and have as their primary goals 1) testing portable instruments for their robustness as field instruments for life detection, 2) assessing Mars analogue environments for biosignatures, 3) refining protocols for contamination reduction, 4) defining a minimal sample suite for Astrobiology science on Mars and 5) sample acquisition, collection and caching on rover platforms: first Cliffbot, then Athena. The goals and technologies used during this ASTEP campaign are very similar to that proposed by the MAX-C mission. We argue in favor of expanding the MAX-C mission concept and present here how tested technologies, procedures, and protocols can be used to address the specific science objectives proposed by the MRRSAG committee and site-specific science goals using Nili Fossae as an example but desirable site.

In each of these expeditions, twenty-five scientists and engineers involved in Mars exploration including MER, MSL, and ExoMars mission team members, conducted instrument testing and simulated Mars surface operations training exercises. Twelve instruments have been deployed in the field, testing their individual capabilities and utility within an instrument suite, as well as the performance during simulated Mars surface operations. The contact and remote sensing instruments include; remote Raman, contact Raman, LIBS, ground penetrating radar (WISDOM), FTIR, PanCam, life marker chip (LMC), and induced native fluorescence detectors. Portable instruments deployed also included field-ready gas chromatograph, Raman spectrometer, FTIR spectrometer, and spectrophotometer for pigments and nutrients. Digital and rover mounted microscopy for imaging was used along with PanCam, Hazcam, and NavCam imagery. The contact instruments were evaluated against analytical suite measurements: MSL

instrument Sample Analysis at Mars simulated by commercially available GCMS and CheMin XRD/XRF by its field derivative, the Ex Situ, Inc. Terra. Samples returned from the field are analyzed by a comprehensive suite of instruments analogous to those that would be used on earth after sample return and include GCMS, GCIRMS, LCMSMS, ToFSIMS, NanoSIMS, two step laser ablation mass spectrometry (UL^2MS), Raman, FTIR, culturing and microbial characterization techniques, light plus electron microscopy.

In the past four expeditions, we have made 12 Rover deployments both with ATHENA and "Cliffbot" on challenging terrain in Svalbard in addition to measurements made by the instruments listed above. Our work also extends to testing Mars sample return technology in several ways; the development and testing of a ATHENA mounted platform system specific for collection of samples via a robotic arm and scoop (Figure 1G), development of protocols and science justification for contact instrument suite for sample targeting, and performance of initial analysis, and development of successful protocols for sterilization in the field to ensure sample integrity (backed up by biotechnology assessments of sample cross contamination (2). The scientific team has developed a close working relationship with the JPL-based rover engineers resulting in initial development of Rover arm sample targeting systems and protocols. As NASA and ESA enter a new era of collaboration, AMASE has provided, and will continue to provide, a test bed for both in situ and Mars Sample Return mission architectures.

Astrobiology Sample Acquisition and Return (ASAR) mission concept

The MAX-C concept primary objectives are listed above. While this mission design is in broad agreement with these goals, more specific science objectives for the ASAR concept are as follows; As a follow on to MSL, identify and classify different past Martian environments with different habitability potentials, characterize their geologic context, investigate abiotic carbon chemistry, search for signatures of the preservation of ancient life markers, and develop criteria that will constitute a set of working hypotheses for the caching of high science yield samples for return to earth.

These objectives balance the need to be a significant extension but responsive to currently planned missions (MSL and ExoMars), the use of in-situ measurement capabilities in selecting the highest science yield samples for earth return and yet not be an unrealistic extension of current technology.

Site and site-specific science

The MRR-SAG have identified Noachian, Noachian / Hesperian terrains as a top priority for the mission. The mission concept proposed here uses the Nili Fossae region of Mars as a model location that is known to contain a diversity of interesting geology. Although other interesting sites may well be identified in the future, Nili Fossae presents the advantage of having been studied extensively as a candidate landing site for MSL. This region includes multiple instances of astrobiological and geochemically relevant lithologies, such as carbonates, clays, basalts, as well as olivine- and pyroxene-rich outcrops. As the region is currently dated at ~3.5 Ga, it represents a unique target to gather information on another planet of the time period when life started on Earth. Furthermore, it has been shown to be within a region of high methane concentrations, which could be addressed with the inclusion of optional instrumentation (see Table 1). Specific science to be addresses by each lithologic type is as follows; *Mafic silicates*- The mafic silicates in this region primarily consist of olivine and pyroxene. The olivine exists as dune deposits and olivine-rich rocks also occur overlaying the phyllosilicate-rich lithologies. The olivine is believed to be either exhumed from depth during the Isidis impact or deposited as a volcanic flow (3). In either case, these rocks will be important for constraining compositions of both the martian interior and of the provenance for the carbonate materials in this region. Sample caching of the olivine bearing-rocks will be a high priority target for potential sample return so that radiometric dating techniques can be used for fine calibration of crater size-frequency distribution dating, mantle oxygen fugacity and the provenance of mantle volatiles (including carbon and water). Figure 1 shows confocal microRaman mapping of macromolecular organic carbon (MMC) associated with spinel grains completely enclosed in an olivine phenocryst in DaG476 (4). Constraining the presence of MMC within olivine and pyroxene lithologies on Mars

for earth return would be a primary mission goal of ASAR. Furthermore, weathering of olivine lithologies (serpentinization) has been postulated to be responsible for the increase in atmospheric concentration of methane in this general area of Mars (5). Assessing the amount of olivine weathering may yield important clues regarding the origin of martian methane. *Phyllosilicates*- Phyllosilicates exposed at Nili Fossae are geologically important because they provide much needed insight into ancient Noachian weathering processes on Mars. Unlike the weathering regimes found to exist at Meridiani Planum and Gusev crater, the presence of Fe/Mg-rich smectite clays indicates weathering processes from waters with neutral to alkaline pH. Given the extensive insight gained about acidic weathering processes on Mars from the MER mission, we stand to gain a tremendous amount of information about this additional martian weathering environment with a rover deployment. The phyllosilicates are also Astrobiologically important because their formation required waters that are more suited for sustaining life than many of the acidic environments encountered by the MER mission. Moreover, the crystal structures of these minerals readily take up biologically important compounds including water, ammonium, and organics, and they have been shown to act as protection against the effects of solar radiation (5,6). Interaction of organic molecules with clay catalysts has been conjectured to be important in the origin of life on earth (7). *Carbonates*- carbonates, like the phyllosilicates, will provide much needed insight into Noachian / early Hesperian weathering processes from waters with neutral to alkaline pH. Coupled with the diagenetic history of the phyllosilicates, it may be possible to investigate any changes in weathering processes indicative of climate change during this critical portion of martian geologic time. The carbonates in the Nili Fossae region of Mars present the optimal target to shed light on the debate as to abiotic (8) versus biotic (9) formation of organic macromolecular carbon in ALH84001. It would appear that both carbonates are of approximately equal age and the instrument suite developed for ASAR is similar to an important subset of that used to detect and characterize the indigenous organic phases in ALH 84001.

Mission Design

The ASAR mission concept would broadly follow the recommendations of the MRRSAG but refine certain aspects of EDL, Rover Design, and instrument payload and deployment. Figure 1 shows the Raman and FTIR point spectroscopy of targets within a PanCam image. This data shows the presence of recognizable mineralogy to the weight percent level. XRD of the same sample allows *definitive* identification of the minerals present and supports both Raman and IR data sets. The inclusion of LDI-ToF (Table 1) allows analysis of the core surface for organic molecules at a detection sensitivity (~1 ppb) far better than that of Raman and IR (~100ppm). This spatially-resolved interrogation of acquired cores would enable the detection and characterization of organic molecules preserved in rock interiors, and it would enable selection of promising samples for caching. The data set generated by this combination of instruments allows both sensitive and spatially resolved mineral and organic characterization.

Rover

The design of the MAX-C mission envisions a mid sized rover between MER and MSL with "go to" and "hazard avoidance" capabilities and a mass of ~300 kg. The cruise and EDL strategy will be similar to that used by MSL i.e. direct injection from the hyperbolic arrival trajectory, guided entry, and powered descent using the sky crane system. This would give a landing ellipse of ~7 km radius. EDL performance will limit access to sites below 1 km in altitude. The rover size itself would remain responsive to the size of the necessary instrument suite, however, it would be a mid sized rover compared to MER and MSL. Power and thermal design considerations would be based on a solar powered vehicle and therefore restrict the mission to between 25^{o}N and 15^{o}S. It is desirable that the maximum traverse distance of the rover would be ~20 km allowing roving outside the landing ellipse (this is ~10 km more than MAX-C) and would allow traverses on sandy slopes to between 10 and 12 degrees but up to 30 degrees on well-consolidated or rock-plated terrain. From assessments of the Nili Fossae site as a landing site for MSL, it has been shown that a rover with these specifications would be able to access all of the interesting lithologies outlined earlier.

Instruments

In the MRR design, a single robot arm is conceived undertaking contact science investigations and sample preparation and caching (rock abrasion and coring). ASAR proposes to use 2 arms, a single arm for instrument deployment and one for sample preparation. The instrument suite developed in Table 1, is a suggested payload and the product of several years field-testing and laboratory analysis of Martian analogue and meteorite samples (items in italics are body mounted and optional, although desirable, see later section – ASAR with no sample return).

Table 1. Suggested instrument suite for ASAR

Component	TRL	Estimated Mass (Kg)	Measurement / Function
Instrument deployment arm	9	25.0	Hold contact instrument suite
Microscopic Vis/IR imager	9 / 5	2.0	Micron scale texture. Spatially resolved molecular bonding information for inorganic and organic carbon detection
Raman point or mapping spectroscopy	7	2.0	Spatially resolved mineralogical and organic carbon detection and mapping
Point reflection XRD/XRF	4/5	4.5	Definitive mineralogy on point selected targets
Laser Desorption Mass Spectrometry	4/5	4.5	Detection of organic species. Allows the acquisition of molecular information to supplement the molecular bonding information from Raman and IR
PanCam + Vis-NIR filtering	9/5	2.5	Wide-angle stereo. High Resolution (mono). Filter sets 400 nm – 1 μm up to 12 filters
Mast	9	3.5	Mount PanCam
Sample Preparation Arm	9	12.0	Hold Sample preparation tools
Coring Drill	3	5.0	For Rock and regolith cores
Rock Abrasion Tool	9	1.0	To clean surface of targets before analysis
Sample Carousel	3	10.0	Contain Rock cores
Cavity Ring Down Spectroscopy / Tunable Laser Spectroscopy	*5/9*	*4.0*	*Concentration and isotopic measurements of methane (see ASAR with no MSR section later in paper).*
Total		**72**	

The MAX-C concept envisions a 15 Kg instrument payload with an additional 50 Kg of supporting payload (25 Kg arm, 9 Kg mast and 16 kg of coring / abrading, caching, bit change out hardware). In both concepts, NavCam and Hazcam imagers are envisaged to be similar to the MER payload and part of the Rover mass. The mass figures for the robotic arms are calculated at approximately twice the weight of the payload they carry (Hayatti personal communication). The ASAR payload currently stands 7 kg greater than that recommended by the MRRSAG (1). However, further detailed mission definition would be needed to constrain these figures for both mission concepts. The suggested instrument suite is designed to provide spatially resolved element, mineralogy, and molecular organic carbon measurements using mutually supportive techniques from the macroscale (PanCam) to the microscale (MI/IR). All of the instruments mentioned have been field or laboratory tested on martian meteorites for their utility to answer the science goals of ASAR. Further details of the instrument suite are as follows;

Microscopic Vis/IR imager

This instrument would provide micron scale textural and chemical bonding data, allowing for the detection of mineral and organic carbon phases.

Raman point / mapping spectroscopy

This instrument will be able to acquire both micro-mineralogical and organic carbon data. It has been developed to a high TRL for both ExoMars and was part of the original payload for the MER rover mission. Including a mapping capability for this instrument would be very desirable. Figure 1 shows both point spectra and confocal microRaman mapping of a spinel inclusion in olivine identifying organic (MMC) phases, illustrating the utility of Raman spectroscopy for mineralogical and organic carbon detection.

Point reflection XRD/XRF
While analytical XRD/XRF has a high TRL for both ExoMars and MSL, these instruments require extensive sample preparation. However, a hydrid powder / single crystal instrument that will work in reflection mode (and hence, become a contact instrument requiring minimal sample preparation such as rock abrasion) are under development using space flight qualified components. This instrument would allow contact definitive mineralogy and elemental measurements to be undertaken.

Laser Desorption Ionization Mass Spectrometry
A vacuum LDI mass spectrometer would require transfer of the sample to be analyzed into the evacuated mass analyzer housing prior to LDI operations. This complexity can be addressed by various methods currently under development, such as ingestion or probe capture of RATed fines, or even by direct laser ablation of surface materials followed by controlled re-deposition on the analytical substrate. This sampling step could be warranted however given some potential advantages: (1) vacuum LDI could be coupled to a TOF analyzer yielding the highest sensitivity for compounds with molecular weights of up to 10 kDa, including key oligomeric biomarkers; (2) the sample could be controllably pre-processed, such as with an LDI-enhancing matrix deposition, to amplify the sensitivity to key classes of organics; and (3) the same instrumentation could be augmented with a second laser source to enable two-step laser desorption of neutral species followed by laser post-ionization. This L2MS technique offers exquisite sensitivity to key classes of astrobiologically-relevant organics such as polycyclic aromatic hydrocarbons with little interference from fragments of other desorbed compounds.

PanCam + Vis-NIR filtering
This instrument is at a high TRL, being deployed on Beagle 2, MER rovers and MSL. Wide angle imaging with filtering would allow broad scale navigation / hazard avoidance as well as geological context on surrounding rocks and outcrops. High Resolution imaging with filtering would allow confirmation of the wide angle images at a finer spatial scale with mineralogical data allowing informed decisions on suitable targets and navigation options to the target.

Sample Caching
This portion of the instrument suite is currently under development. AMASE has tested a scoop regolith caching system with the ATHENA rover (TRL 6). Coring drills are under development for ExoMars and MSR. Caching of cores is also under development through internal JPL funding. Further details can be found in the Critical Technology development white paper from MEPAG. The core itself would be similar to that described in the MRRSAG white paper: cores 8 – 10mm in diameter and 50 mm long, with a cache system capable of containing 19 cores in a close packed hexagonal pattern. By pushing any core collected in front of the instrument suite, spatially resolved measurements on freshly revealed surfaces could be undertaken.

Robotic arms
Two robotic arms, each with preferably 5 degrees of freedom, are envisaged for this mission concept. Estimates of the mass of a robotic arm to hold an instrument payload of a certain mass vary from 0.8 – 4 times payload mass. Splitting the sample preparation from contact instruments ensures flexibility during instrument deployment and reduces risk if sample acquisition causes undue vibration or malfunctions completely. Development of lightweight capable robotic arm technology to hold a 15kg payload within the mass constraints of the mission would be key to mission viability.

Critical Technology Development

These are focused development goals for this mission concept and while most are covered by the MRRSAG white paper, there are a few critical developments needed for this mission scenario. The time line for investment and realization of new technology may focus this mission on the 2020 launch window, however, all of the technologies listed for this mission are currently funded projects if not already at the highest TRL. Focused technology needed for the ASAR mission are; continued development of laser desorption ionization Time of Flight (LDI-ToF),

continued development of reflection contact XRD/XRF, continued development of microscopic IR and Raman imaging systems, methods for landing in a potentially high wind shear area (Nili Fossae), sample coring and caching, light weight capable robotic arm for payload deployment, planetary protection and sample receiving / analysis facilities.

Planetary Protection

As this mission is a potential life detection and earth return mission, it would be category IVB for the rover and instrument but category V for the cache. Due to the lack of an analytical suite, certain problems during bake out of the instrument are eliminated. However, no mission has needed a category V requirement for planetary protection previously, and therefore these considerations must be in the forefront of the cache design. AMASE has extensively tested cleaning and contamination mitigation and detection technologies (2).

Compatibility with ExoMars

The mission architecture discussed here is one that is complimentary and not competitive to the science goals of ExoMars as reviewed in the MRRSAG report (1). At the time of writing this document, the present understanding for the 2018 mission opportunity is that it will be carried out within the framework of a NASA-ESA cooperation program for Mars exploration. The 2018 mission will land two rovers on the same location: NASA's Mars Astrobiology Explorer and Cacher (MAX-C) rover, and ESA's ExoMars rover. This document presents a mission concept for the MAX-C rover. We consider that the proposed scheme is valid both in case MAX-C flies together with ExoMars or in a different launch opportunity.

ASAR with no or a "ground breaking" Sample Return Architecture.

This white paper fully endorses both the MAX-C mission concept and the idea that Mars Sample Return (MSR) has been highlighted as the highest priority for the Mars program (1,10,11,12). However, it is clear that if MSR is too expensive or that a "ground Breaking MSR (GB-MSR) architecture is deemed most effective, that ASAR could become the basis of a Robotic mission that could still yield tremendous science return at a very exciting Mars site. A suggested architecture would then add the LDI-ToF, a second microscopic imager, and point XRD/XRF to a simplified carousel to house a single core. These instruments could then be used to gain spatially resolved measurements on cored rock samples and free instrument mass from the robotic arms. The remaining arm mounted contact instruments would then be used to conduct primary science goals and assess samples for suitability of coring and presenting to the carousel based instruments. Furthermore, a tunable laser or cavity ring down spectroscopy instrument could also be added (See Table 1) to detect and measure the isotopic composition of methane in the atmosphere.

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Figure 1. A) ATHENA rover with sample scoop and caching carousel deployed on AMASE 09. B) Close-up of robotic arm placing a scoop containing sample into the scoop housing within the caching box. C) PanCam image of basalt flow containing peridotite xenoliths and carbonate basalt breccia. D) Field acquired spot Raman of the major phases from outcrop shown in C. E) powder XRD of the same basalt,point XRD would be used by ASAR F) Field deployed hand held IR results showing C=O and Si-O stretching modes on this basalt. G) MicroRaman map of an inclusion 4 µM beneath the surface of an olivine phenocryst in martian meteorite DaG 476, yellow – olivine, green – spinel (magnetite), red – pyroxene, blue – organic macromolecular carbon. H) Laser desorption ionization mass spectrometry of an area of Dag 476 *a* – blank, b) PAH distribution from MMC extracted from the Murchison meteorite *c*) PAH distribution in an inclusion rich area of DaG 476.